

Supplementary to

EU forest carbon sink decline as seen by Earth observation and national inventories

5 Nora Linscheid¹, Laura Mayer¹, Chiara Aquino², Manuela Balzarolo², Maria Vincenza Chiriaco²,
Mélodie Juillard³, Martin Brandt⁴, Emilio Chuvieco⁵, Philippe Ciais⁶, Maoyuan Feng⁷, Rasmus
Fensholt⁴, Teja Kattenborn⁸, Amin Khairoun⁵, Katja Kowalski⁹, Siyu Liu⁴, Joachim Maack⁸, Clemens
Mosig¹, Pierre Regnier⁷, Cornelius Senf⁹, Alba Viana-Soto⁹, Yidi Xu^{6,10}, Yanzi Yan⁷, Ana Bastos¹

10 ¹ Institute for Earth System Science and Remote Sensing, Leipzig University, Leipzig, Germany

² CMCC Foundation, Euro-Mediterranean Centre on Climate Change, Viterbo, Italy

³ Citepa, Paris, France

⁴ Department of Geosciences and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark

⁵ Department of Geology, Geography and the Environment, University of Alcalá

15 ⁶ Laboratoire des Sciences du Climat et de l'Environnement, LSCE/IPSL, CEA-CNRS-UVSQ, Université Paris-Saclay,
91191 Gif-sur-Yvette, France

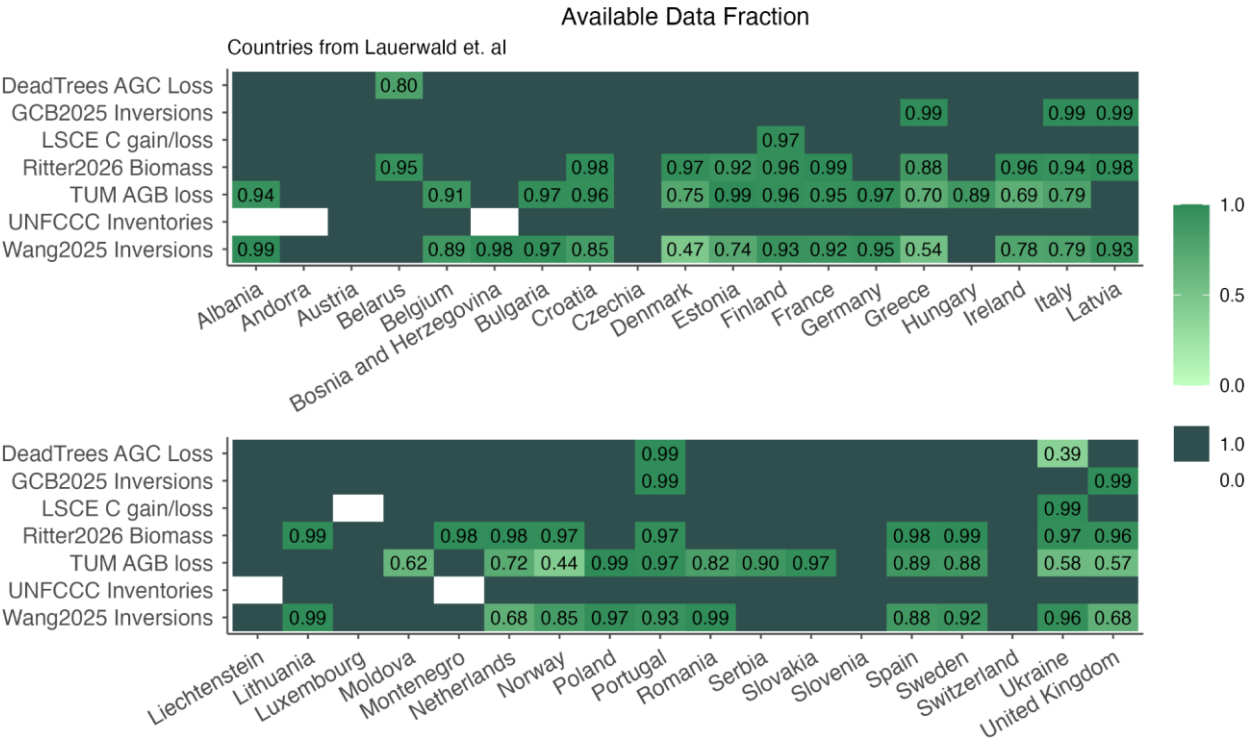
⁷ Department Geoscience, Environment and Society, Biogeochemistry and Modelling of the Earth System-BGEOSYS,
Université Libre de Bruxelles, Brussels, Belgium

⁸ Chair of Sensor-based Geoinformatics, University of Freiburg

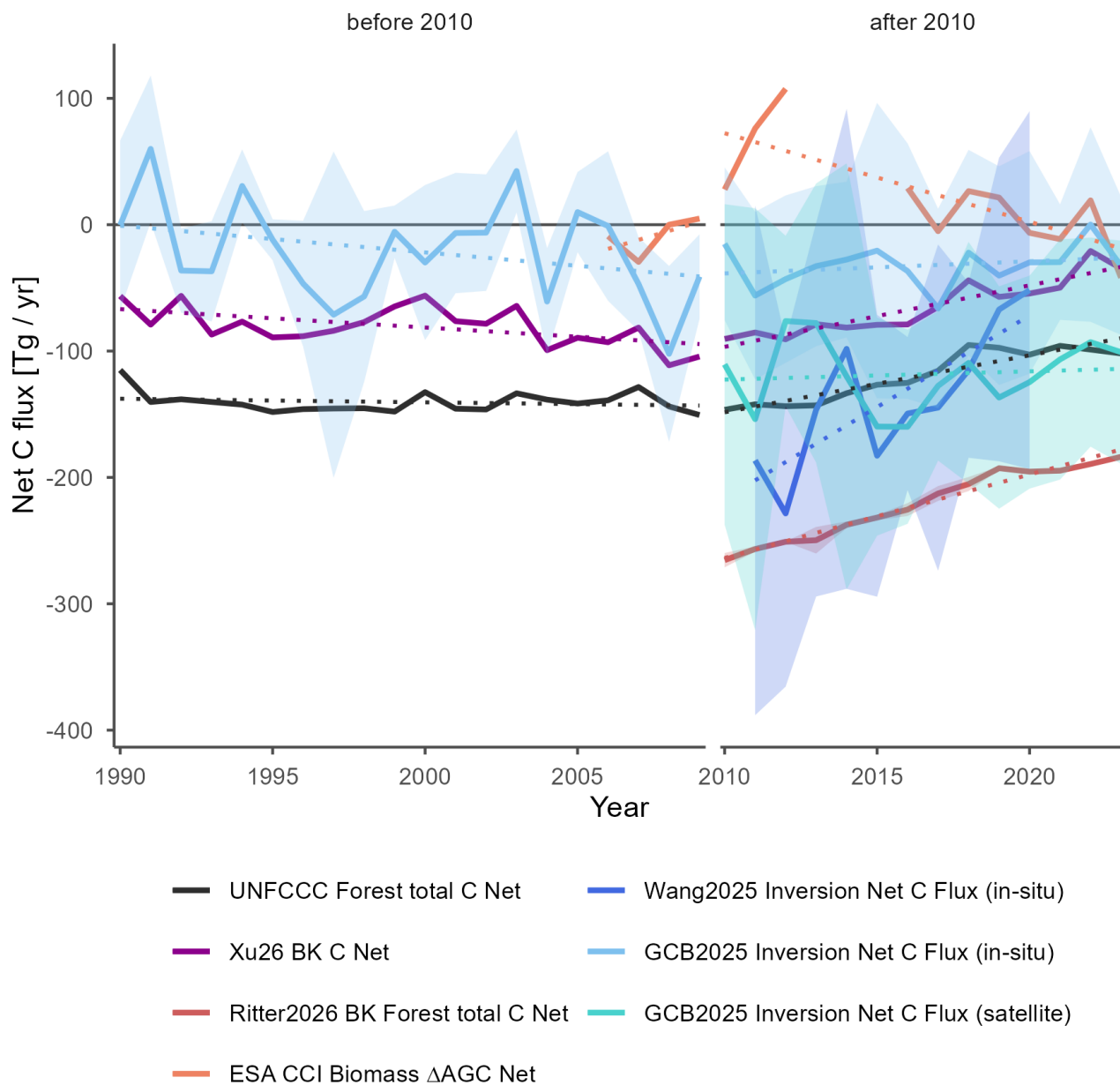
20 ⁹ Technical University of Munich, School of Life Sciences, Earth Observation for Ecosystem Management

¹⁰ School of Ecological and Environmental Sciences, East China Normal University, Shanghai, China

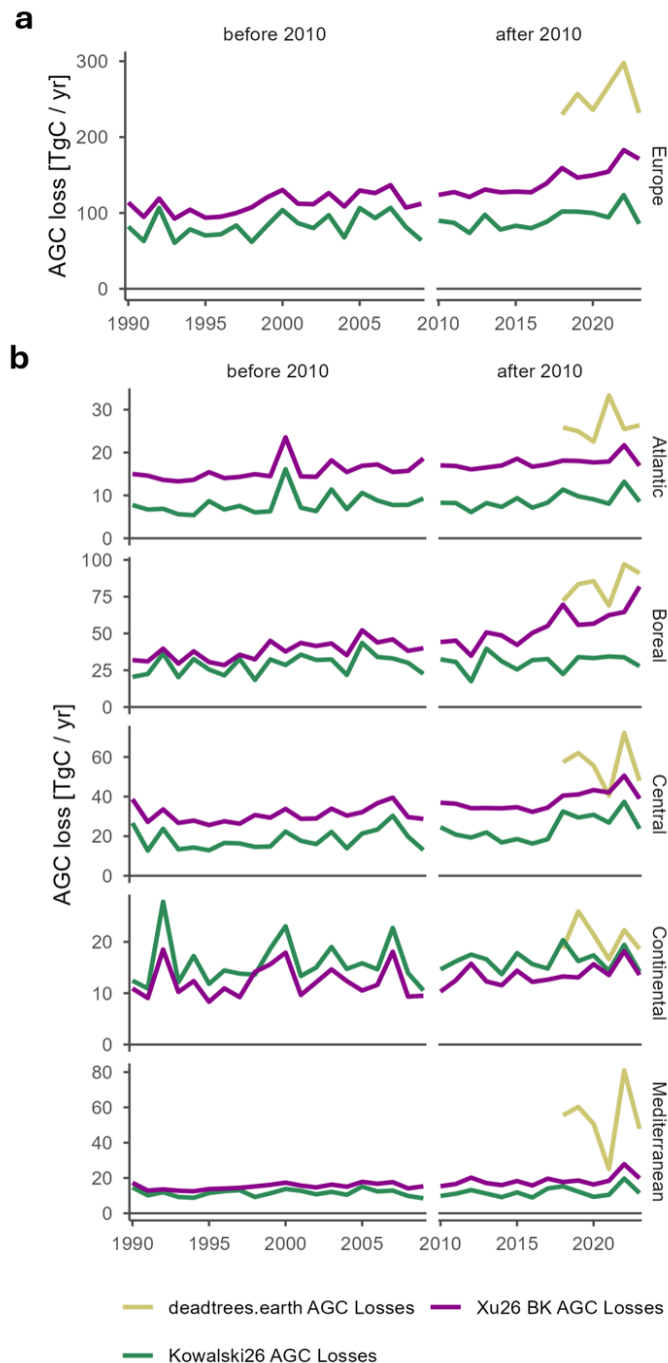
Correspondence to: Nora Linscheid (nora.linscheid@uni-leipzig.de), Ana Bastos (ana.bastos@uni-leipzig.de)



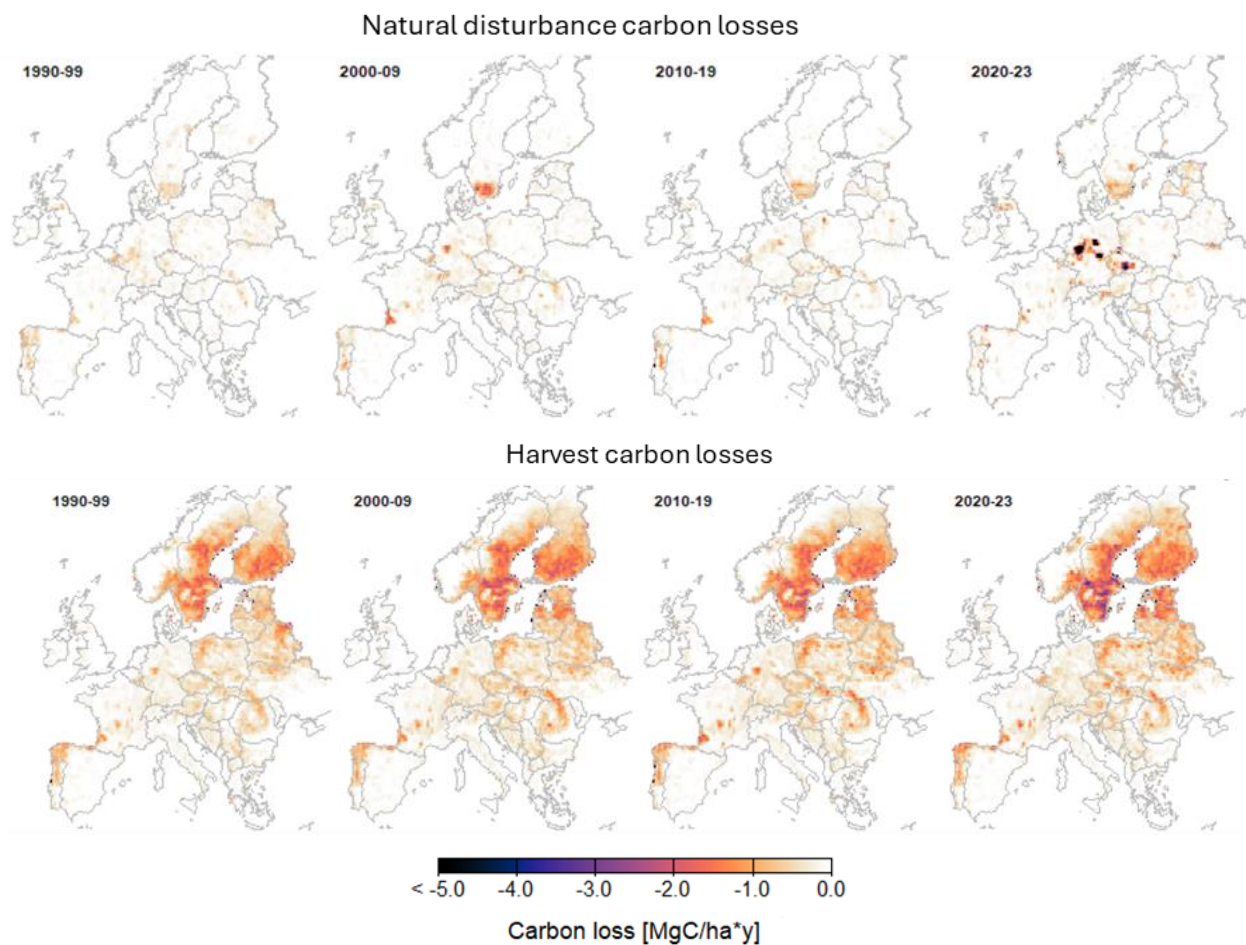
30 **Sup. Figure S1: Data coverage per country and dataset.** For gridded datasets with temporal dimension, only pixels without any available data over the whole time period were considered missing.



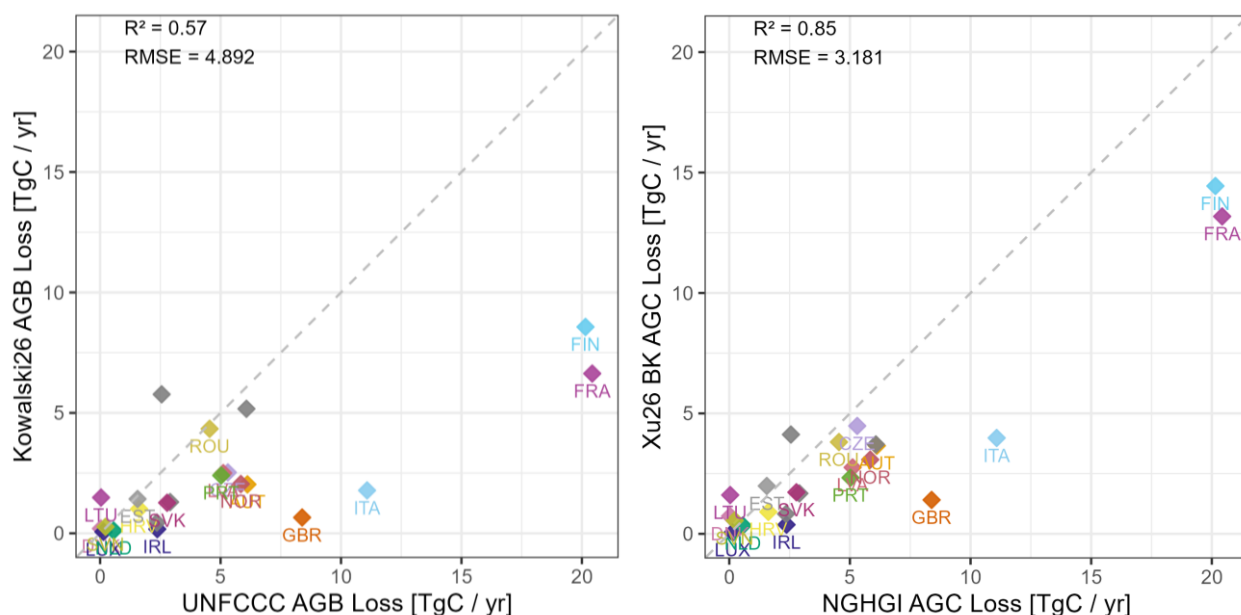
Sup. Figure S2 - Trends in temporal development of net forest carbon fluxes over Europe across different datasets.



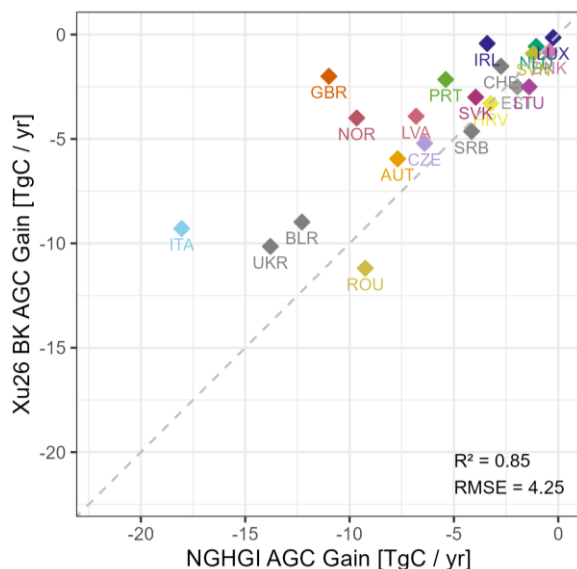
35 **Sup. Figure S3: Time series of forest aboveground carbon losses from different estimates** for a) Europe and b) three most affected European regions, comparing the temporal windows 1990-2009 and 2010-2023. Positive values represent aboveground carbon losses. Dotted lines show linear trends for each time period. AGC: Aboveground carbon. This analysis is based on all countries in the study area.



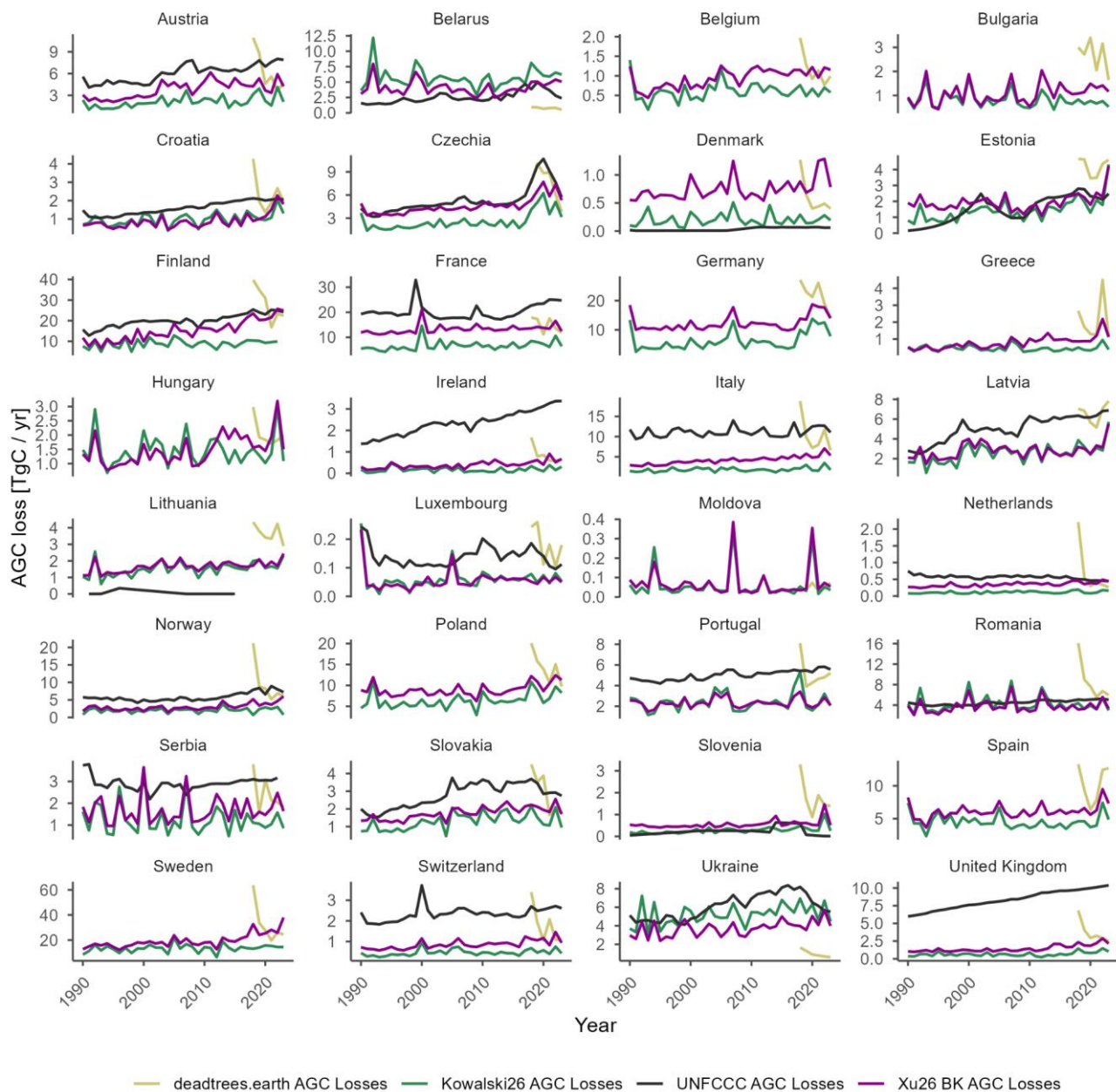
Sup. Figure S4: Forest carbon losses over Europe from Kowalski2026, separated into decadal periods of 1990-1999, 2000-2009, 2010-2019, and remaining recent years 2020-2023, for natural losses (top) and harvest losses (bottom).



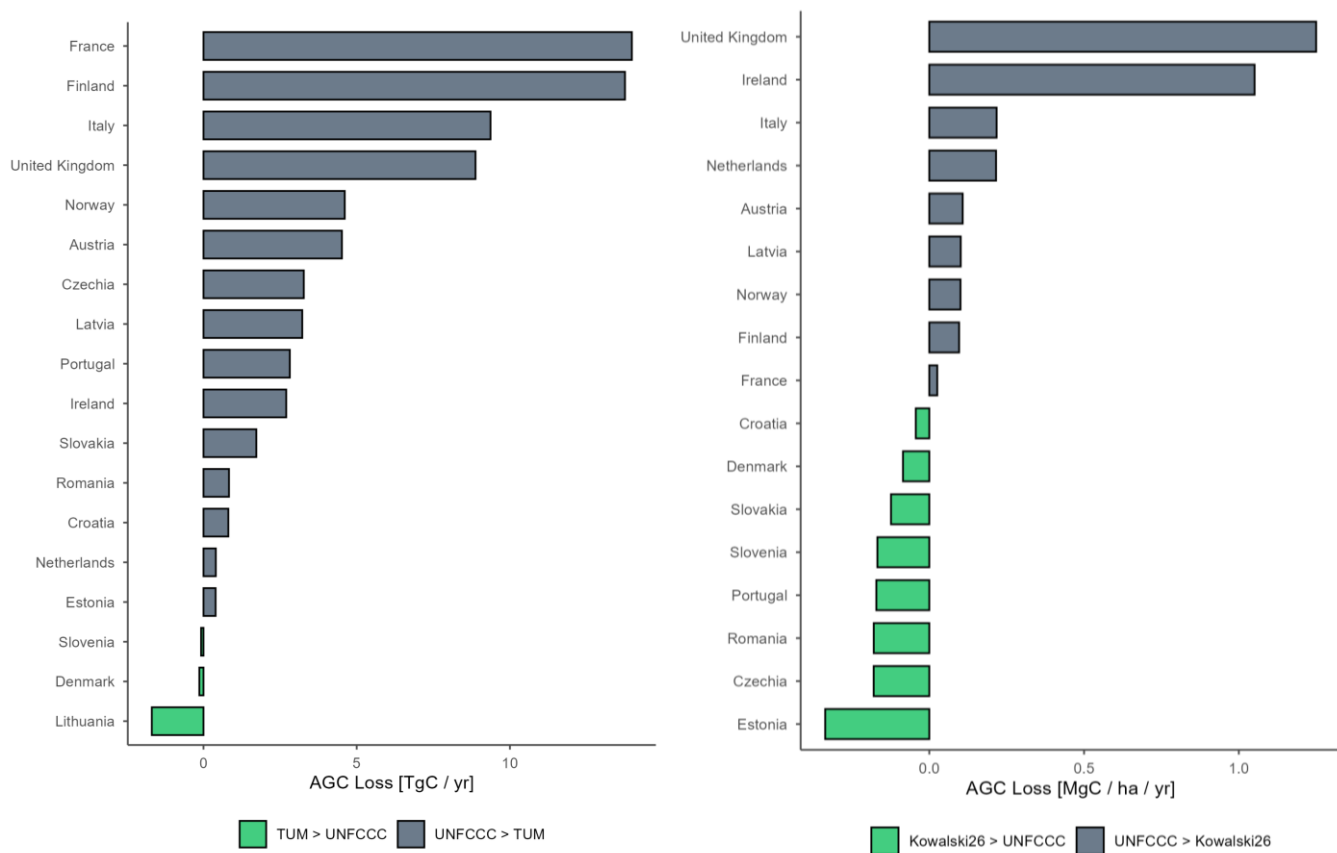
45 **Sup. Figure S5: Comparison of AGB losses from EO and NGHGI.** Average annual losses per country between 1990-2023 are displayed. No distinction of gains and losses is made in NGHGI of Belgium, Bulgaria, Hungary, Germany, Greece, Malta, Moldova, Spain, Sweden, and Poland (marked with unfilled outline markers), which explains parts of the deviation. The 1:1 line is indicated by the dashed grey line. Colors are assigned to each country for easier identification across subplots.



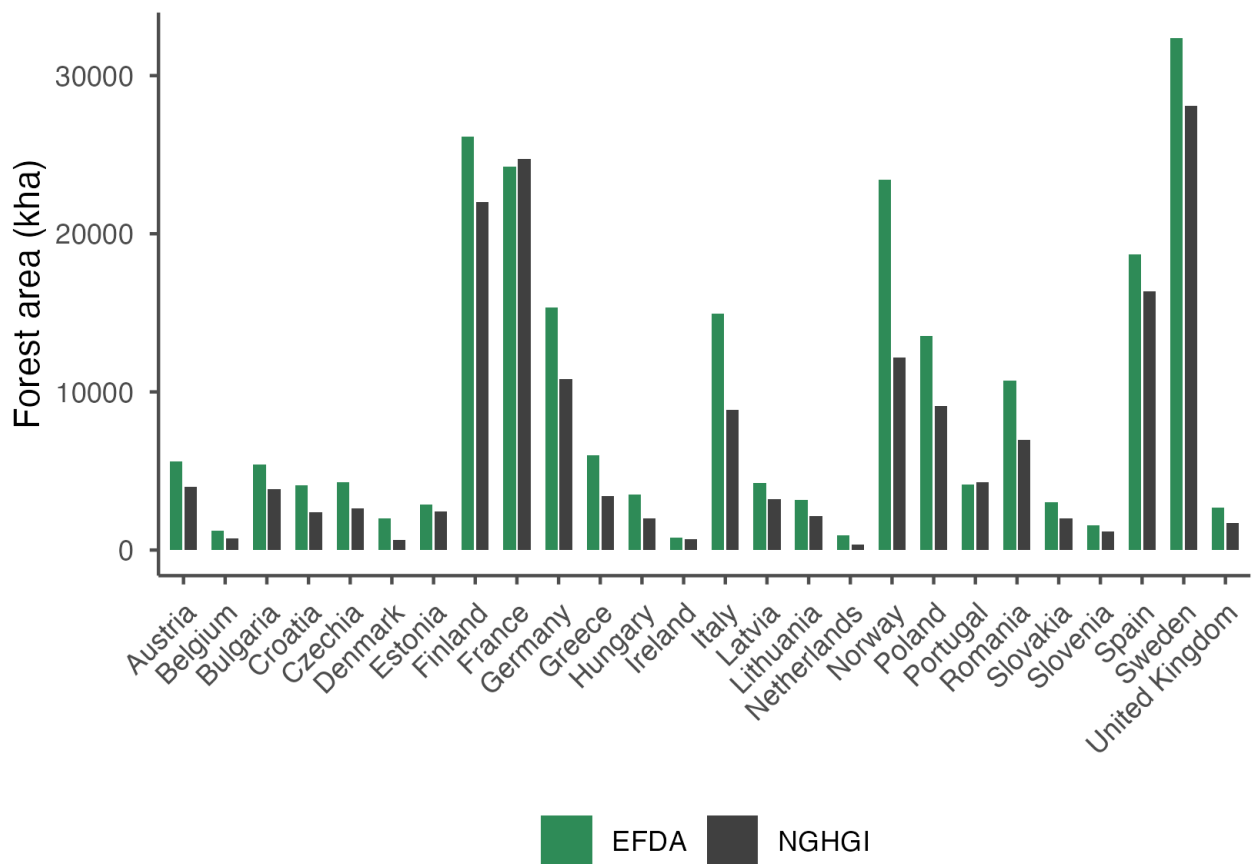
50 **Sup. Figure S6: Comparison of AGB gains from EO and NGHGI.** Average annual losses per country between 1990-2023 are displayed. No distinction of gains and losses is made in NGHGI of Belgium, Bulgaria, Hungary, Germany, Greece, Malta, Moldova, Spain, Sweden, and Poland, so they were excluded from this comparison. Note that axes are not identical: The 1:1 line is indicated by the dashed grey line.



Sup. Figure S7: Net carbon losses for all European countries not shown in Fig. 6. Note different y-axes.

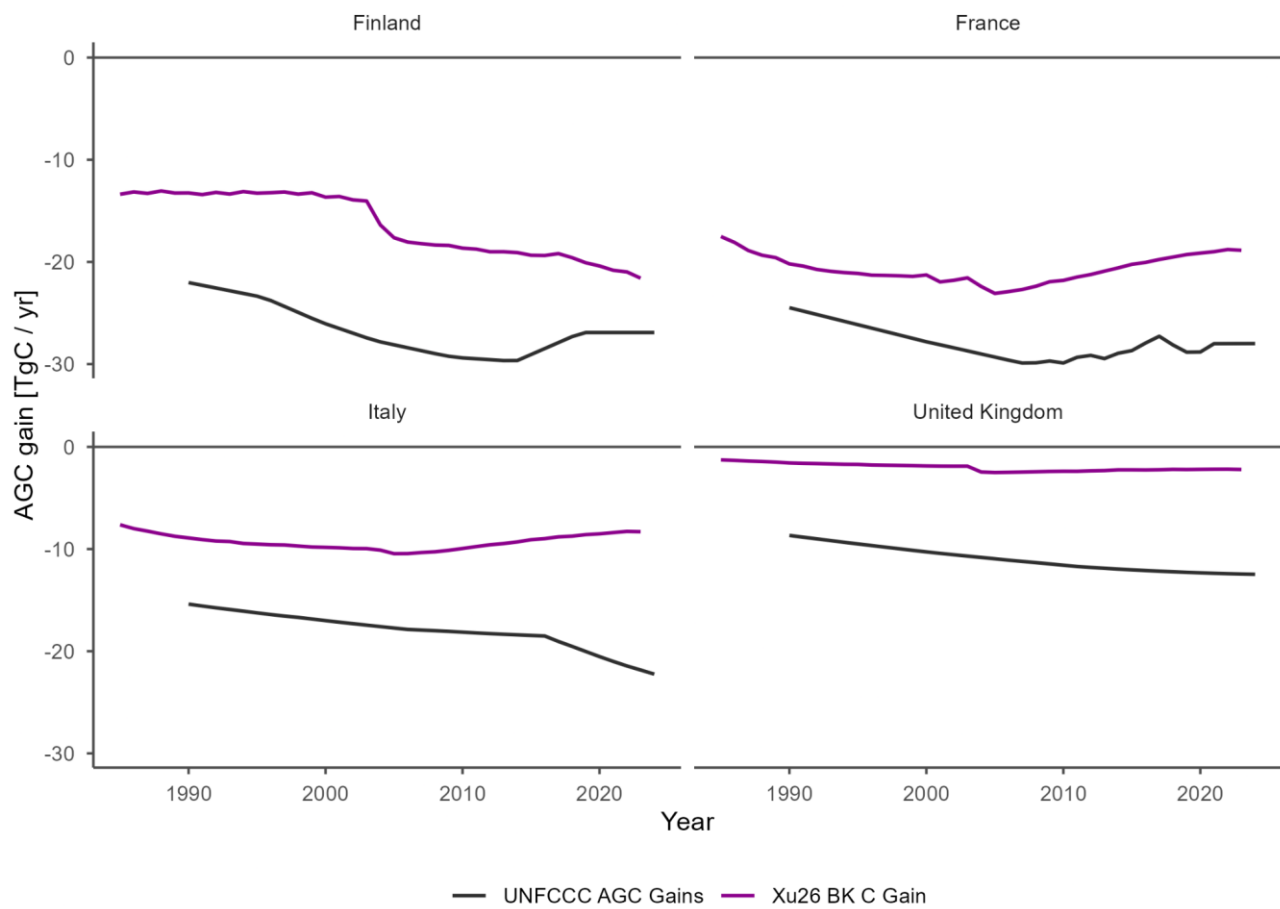


Sup. Figure S8: Comparison of aboveground forest C losses per country estimated by NGHGs and Kowalski 26.



60 p

Sup. Figure S9: Comparison of forest area per country estimated by NGHGI and EFDA.



65 Sup. Figure S10: Time series of net carbon gains for four selected European countries.

Supplementary Tables

Sup. Table S1 - Overview of regional separation of the European continent.

Region	Countries
Atlantic	Belgium, France, Ireland, Luxembourg, Netherlands, United Kingdom
Boreal	Denmark, Estonia, Finland, Latvia, Lithuania, Norway, Sweden
Central	Austria, Czechia, Germany, Hungary, Poland, Slovakia, Switzerland
Continental	Belarus, Bulgaria, Moldova, Romania, Ukraine
Mediterranean	Croatia, Greece, Italy, Portugal, Serbia, Slovenia, Spain

Sup. Table S2: Net Forest C sink trend estimates for Sup. Fig. S2

Variable	Region	slope 1990-2009 [TgC/yr]	slope 2010-2023 [TgC/yr]	Slope ratio
UNFCCC Forest total C Net	Atlantic	-18,1	-18,0	1,00
Ritter2026 Forest total C Net	Atlantic	-39,6	-29,1	0,74
Xu26 BK C Net	Atlantic	-9,5	-5,4	0,57
GCB2025 Inversion Net C Flux (in-situ)	Atlantic	-4,1	0,3	-0,07
GCB2025 Inversion Net C Flux (satellite)	Atlantic	-7,8	-1,6	0,21
Wang2025 Inversion Net C Flux (in-situ)	Atlantic	-27,7		
UNFCCC Forest total C Net	Boreal	-29,9	-17,8	0,60
Ritter2026 Forest total C Net	Boreal	-43,0	-32,3	0,75
Xu26 BK C Net	Boreal	-9,0	3,7	-0,41
GCB2025 Inversion Net C Flux (in-situ)	Boreal	-9,7	-14,9	1,53
GCB2025 Inversion Net C Flux (satellite)	Boreal	-41,2	-40,6	0,99
Wang2025 Inversion Net C Flux (in-situ)	Boreal	-29,6		
UNFCCC Forest total C Net	Central	-35,7	-13,1	0,37
Ritter2026 Forest total C Net	Central	-50,4	-38,7	0,77
Xu26 BK C Net	Central	-17,0	-7,7	0,45
GCB2025 Inversion Net C Flux (in-situ)	Central	-7,9	-5,1	0,65
GCB2025 Inversion Net C Flux (satellite)	Central	-37,6	-27,2	0,72
Wang2025 Inversion Net C Flux (in-situ)	Central	-82,3		
UNFCCC Forest total C Net	Continental	-34,7	-32,5	0,93
Ritter2026 Forest total C Net	Continental	-51,3	-48,2	0,94
Xu26 BK C Net	Continental	-23,4	-19,5	0,83
GCB2025 Inversion Net C Flux (in-situ)	Continental	-5,8	-6,9	1,19
GCB2025 Inversion Net C Flux (satellite)	Continental	-34,0	-28,7	0,84
Wang2025 Inversion Net C Flux (in-situ)	Continental	7,5		
UNFCCC Forest total C Net	Mediterranean	-17,5	-18,4	1,06
Ritter2026 Forest total C Net	Mediterranean	-48,5	-44,5	0,92
Xu26 BK C Net	Mediterranean	-19,8	-11,0	0,56
GCB2025 Inversion Net C Flux (in-situ)	Mediterranean	-1,1	3,6	-3,36
GCB2025 Inversion Net C Flux (satellite)	Mediterranean	-18,1	-8,1	0,45
Wang2025 Inversion Net C Flux (in-situ)	Mediterranean	-14,5		
UNFCCC Forest total C Net	Europe	-135,9	-99,9	0,73
Ritter2026 Forest total C Net	Europe	-232,8	-192,8	0,83
Xu26 BK C Net	Europe	-78,8	-39,9	0,51
GCB2025 Inversion Net C Flux (in-situ)	Europe	-28,5	-23,0	0,80
GCB2025 Inversion Net C Flux (satellite)	Europe	-138,7	-106,2	0,77
Wang2025 Inversion Net C Flux (in-situ)	Europe	-146,6		

Sup. Table S3: Trend estimates of forest C losses for Fig. 3

Variable	Region	Slope 1990-2009 [TgC / yr]	Slope 2010-2023 [TgC / yr]	Slope ratio
DeadTrees AGB Loss	Atlantic	0,47		
TUM AGC total Losses	Atlantic	0,24	0,14	1,74
UNFCCC AGC Losses	Atlantic	0,83	0,10	7,86
Xu26 BK C Loss	Atlantic	0,18	0,16	1,12
DeadTrees AGB Loss	Boreal	2,21		
TUM AGC total Losses	Boreal	0,03	0,24	0,14
UNFCCC AGC Losses	Boreal	0,77	0,44	1,74
Xu26 BK C Loss	Boreal	1,20	0,44	2,69
DeadTrees AGB Loss	Central	-1,66		
TUM AGC total Losses	Central	0,23	0,13	1,74
UNFCCC AGC Losses	Central	0,44	0,38	1,15
Xu26 BK C Loss	Central	0,12	0,19	0,61
DeadTrees AGB Loss	Continental	0,10		
TUM AGC total Losses	Continental	0,06	0,02	3,15
UNFCCC AGC Losses	Continental	0,01	0,21	0,05
Xu26 BK C Loss	Continental	0,23	0,02	11,2 0
DeadTrees AGB Loss	Mediterranean	-2,18		
TUM AGC total Losses	Mediterranean	0,11	0,03	3,17
UNFCCC AGC Losses	Mediterranean	0,11	0,10	1,12
Xu26 BK C Loss	Mediterranean	0,23	0,10	2,30
DeadTrees AGB Loss	Europe	0,27		
TUM AGC total Losses	Europe	0,67	0,56	1,19
UNFCCC AGC Losses	Europe	2,15	1,23	1,74
Xu26 BK C Loss	Europe	1,96	0,92	2,12

Country	Crown cover (%)	Height (m)	Area (ha)	Minimal width (m)	Qualitative forest-land definition (concise)
Austria	30	2	0,05	10	Includes temporarily unstocked areas linked to forest management (e.g. roads, storage sites and glades), short-rotation areas with ≥ 10 -year rotation, forest arboreturns and wooded park areas; excludes fruit/nut plantations and rows of trees outside forests.
Belgium	20	5	0,5	-	Includes areas with vegetation expected to reach the required thresholds.
Bulgaria	10	5	0,1	10	Includes natural regeneration outside urban areas (>0.1 ha), temporarily unstocked forest expected to recover within 10 years, protective belts and qualifying tree lines; excludes city parks, shelter belts and isolated tree rows.
Croatia	10	2	0,1	-	Includes land under forest management, including temporarily unstocked forest; excludes productive forest land without tree cover, roads wider than 3 m and nurseries.
Cyprus	10	5	0,3	-	Includes forest roads, cleared tracks, firebreaks, small open areas within forests, and burnt or temporarily unstocked areas expected to recover through natural or assisted regeneration.
Czechia	30	2	0,05	-	Excludes permanently unstocked cadastral forest land such as forest roads, nurseries and land under power-transmission lines.
Denmark	10	5	0,5	20	Includes temporary non-wooded areas, firebreaks and small open areas that form an integral part of the forest; also includes Christmas-tree areas.
Estonia	30	2	0,5	-	Includes temporarily unstocked areas caused by harvesting or natural disturbances that are expected to revert to forest, as well as qualifying young stands and afforested/reforested areas.
Finland	10	5	0,25	20	Includes parks and yards only when their vegetation characteristics meet the forest definition.
France	10	5	0,5	20	Includes forest roads and openings <20 m wide, windbreaks and forest belts, plantations and short-rotation woody crops meeting the forest criteria; excludes most agroforestry systems and land primarily used for non-forest purposes.
Germany	10	5	0,1	-	Includes forest roads, clearings, glades, firebreaks, landings, rides, nurseries, timber storage areas and other areas serving forest functions; includes certain wooded non-forest formations, while some narrow features and watercourses do not interrupt forest continuity.
Greece	25	2	0,3	-	No additional qualitative criteria are specified.
Hungary	30	5	0,5	-	Includes forest land categories and associated roads or other areas managed under forest management but not currently covered by trees.
Ireland	20	5	0,1	20	Includes public and private plantation forests, recently clear-felled areas, tree growing for flowers/fruits, shrub species and rhododendron; excludes other open areas within forest boundaries.
Italy	10	5	0,5	-	Includes forest roads, cleared tracks, firebreaks and other open areas

					within forests, as well as temporarily unstocked areas expected to regenerate; includes plantations such as poplar and short-rotation coppice; excluding arboriculture plantations such as orchards.
Latvia	20	5	0,1	20	Includes young natural or planted stands expected to reach forest thresholds and areas temporarily unstocked by human intervention or natural causes that are expected to return to forest.
Lithuania	30	5	0,1	10	Includes tree lines up to 10 m wide along fields, roads, water bodies and other sites, as well as single trees and bushes and park/planted areas not defined as forest.
Luxembourg	10	5	0,5	-	Includes temporarily unstocked areas directly connected with forest management, short-rotation areas with ≥ 10 -year rotation, forest arboretums and wooded park areas; excludes fruit/nut plantations and rows of trees outside forests.
Malta	30	5	1	-	No additional qualitative criteria are specified.
Netherlands	20	5	0,5	30	Includes temporarily unstocked areas directly linked to forest management expected to regenerate in the near future.
Poland	10	2	0,1	10	Includes young stands and plantations expected to reach the forest thresholds and areas temporarily unstocked by harvesting or natural disturbance that are expected to revert to forest.
Portugal	10	5	1	20	Includes temporarily unstocked areas such as clear-felled sites and fire-affected stands expected to recover.
Romania	10	5	0,25	20	Excludes tree rows, dead trees, clear-cuts and forest nurseries are classified separately.
Slovakia	20	5	0,3	20	Includes land covered by tree species serving forest functions and land where forest stands have been temporarily removed to support regeneration or forest nurseries.
Slovenia	10	5	0,25	-	Includes abandoned agricultural land undergoing natural forest expansion when it exceeds 0.5 ha, has been abandoned for >20 years, reaches ≥ 5 m height and has 75–100% tree cover.
Spain	20	3	1	25	Includes young or recently clear-felled stands.
Sweden	10	5	0,5	-	Includes land expected to reach forest thresholds and certain mine areas under restoration; permanent forest roads wider than 20 m are excluded.